



**Prof. Mario L. Ferrari**

**Sustainable Energy**  
**Mod. 6 Fuel Cells & Distributed Generation Systems**

**Dr. Ing. Mario L. Ferrari**

Thermochemical Power Group (TPG) - DIMSET – University of Genoa, Italy

**Lesson III: fuel cells (influence of properties)**

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## Variables Affecting Cell Performance

- Operating variables

- ✓ Current density
- ✓ Temperature
- ✓ Pressure
- ✓ Gas composition

- Cell design

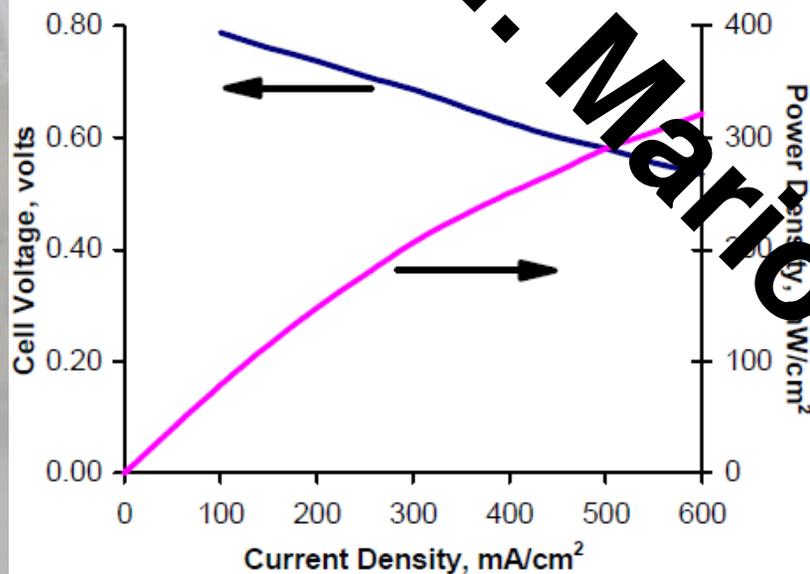
- Other factors

- ✓ Impurities
- ✓ Cell life

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## Current Density Effect

- Activation, ohmic and concentration losses reduce fuel cell voltage (and efficiency)
- This figure shows the linear zone (typical operative zone)



- Fuel cell efficiency increases at part load conditions (this aspect is different from conventional energy systems)
- Since plant component efficiency decreases at part load, system efficiency is almost constant with load variation

- Power density has a peak trend (maximum at high current density)
- Operations around the peak are characterized by low efficiency performance
- Moreover, operations close to the peak can cause instability problems
- Usual operations at the left side of the power density peak to have a compromise between low operating cost (high cell efficiency at high voltage/low current density) and low capital cost (less cell area at low voltage/high current density)

## Temperature Effect

$$\left(\frac{\partial E}{\partial T}\right)_p = \frac{\Delta S}{nF}$$

- Since entropy change ( $H_2O$  reaction) is negative, the reversible potential of the  $H_2/O_2$  fuel cell decreases with an increase in temperature (by  $0.84 \text{ mV}/^\circ\text{C}$ , assuming reaction product is liquid water).
- Moreover temperature has a strong influence on other factors:
  - ✓ Electrode reaction rates. Typically, electrode reactions follow Arrhenius behaviour. As a consequence, these losses decline exponentially with increasing temperature.
  - ✓ Ohmic losses. The impact of temperature on cell resistance is different for different materials. For metals, the resistance usually increases with temperature, while for electronically and ionically conductive ceramics it decreases exponentially. For high-temperature fuel cells, the net effect is a significant reduction in resistance, while for low-temperature fuel cells the impact over the operating range is limited.
- Mass transport processes are not strongly affected by temperature changes

## Pressure Effect

$$\left(\frac{\partial E}{\partial P}\right)_T = \frac{-\Delta V}{nF}$$

- Since volume change ( $H_2/O_2$  reaction) is negative, the reversible potential of the  $H_2/O_2$  fuel cell the reversible potential increases with an increase in pressure (with the square root of the pressure, assuming pressure is equal on both electrodes)

- Moreover pressure increase has beneficial effects on performance:

- ✓ Gas solubility, and mass transfer rates are higher.
- ✓ Electrolyte loss by evaporation is reduced.
- ✓ System efficiencies increase.

- However a pressure increase generate cost increase for material costs (e.g. pipes, stack vessels)

## Reactant Utilization and Composition Effect (1/2)

• Reactant utilization and gas composition have high impacts on fuel cell efficiency. From the Nernst equations: **fuel and oxidant gases containing higher partial pressures produce a higher cell voltage.**

• Fuel utilization factor for  $H_2$  reaction is:

$$U_f = \frac{H_{2,in} - H_{2,out}}{H_{2,in}} = \frac{H_{2,consumed}}{H_{2,in}}$$

In a MCFC fuel utilization factor can exceed the  $H_2$  value for the shift reaction: more  $H_2$  can be produced from CO (  $CO + H_2O \rightleftharpoons H_2 + CO_2$  )

• Fuel utilization factor for MCFC reaction is:

$$U_f = \frac{H_{2,consumed}}{H_{2,in} + CO_{in}}$$

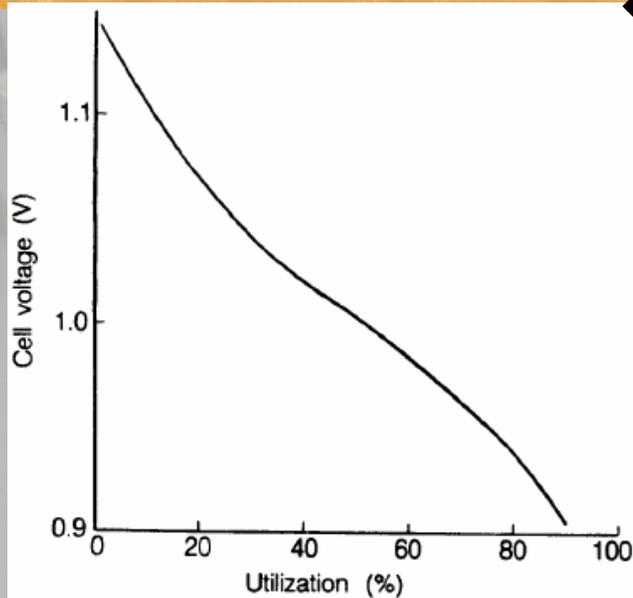
Gas composition changes between the inlet and outlet of a fuel cell, caused by the electrochemical reaction, lead to reduced cell voltages. **The cell voltage can not exceed the minimum (local) value of the Nernst potential.**

# Reactant Utilization and Composition Effect (2/2)

•For a MCFC Nernst equation can be expressed (function of reactant utilization and pressure):

$$E = E^{\circ} + \frac{RT}{2F} \ln \frac{X_{H_2} X_{O_2}^{1/2} X_{CO_2, cathode} P^{1/2}}{X_{H_2O} X_{CO_2, anode}}$$

•The cell reversible voltage function of reactant utilization is shown in the following figure (650°C and 1 atm):



**Reversible voltage decreases with fuel utilization increase!!**

Outlet compositions

Gas	Utilization <sup>a</sup> (%)				
	0	25	50	75	90
<b>Anode<sup>b</sup></b>					
X <sub>H2</sub>	0.45	0.410	0.216	0.089	0.033
X <sub>CO2</sub>	0.064	0.139	0.262	0.375	0.436
X <sub>CO</sub>	0.130	0.078	0.063	0.033	0.013
X <sub>H2O</sub>	0.161	0.378	0.458	0.502	0.519
<b>Cathode<sup>c</sup></b>					
X <sub>CO2</sub>	0.600	0.581	0.545	0.461	0.316
X <sub>O2</sub>	0.300	0.290	0.273	0.231	0.158